Characterization of Dynamic Stall on the UH-60A

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Under severe loading conditions dynamic stall will occur intermittently on a helicopter rotor blade as it makes one revolution of 360 degrees. When dynamic stall does occur, a vortex is shed from the leading edge of the blade; this vortex is translated back along the upper surface of the blade, and then leaves the trailing edge. The shedding of the dynamic-stall vortex in these conditions twists the rotor blade and causes extremely high loads in the helicopter's control system. Indeed, the size and strength of the components in the control system are generally determined by these dynamic-stall loads. Unfortunately, analytical models are unable to compute the dynamic-stall loads because of the nonlinear nature of the aerodynamic loading. A first step in the development of improved analytical models for helicopter design is an accurate characterization of dynamic stall as it occurs in flight as determined by experimental measurements.

A highly instrumented rotor was installed on a UH-60A helicopter, and flight measurements were obtained for a great variety of conditions at Ames in 1993–94. The instrumentation included 242 pressure transducers mounted at nine radial stations on one rotor blade. The variation in measured pressure as the blade makes one revolution can be examined in detail and, with the assistance of two-dimensional wind tunnel tests, regions of dynamic stall can be identified. For the research discussed here, three flight cases were examined. In the first, the helicopter was pulled up very rapidly in an evasive maneuver. This is the so-called UTTAS pull-up, named after the original military requirement for this aircraft: the Utility Tactical Transport Aerial System. This maneuver is quite unsteady and there is a rapid variation in load factor and airspeed. In the second, a high-speed diving turn was examined; this is a steadier maneuver in that the airspeed and load factor are held constant, but the aircraft rates are unsteady. In the third, the helicopter was in level flight, but in an overloaded condition.

From the pressure data measurements it was possible to identify dynamic-stall cycles that involved the repeated shedding of a dynamic-stall vortex as the rotor blade moved through a full revolution. The figure shows a rotor map of the locations of these dynamic-stall events; it can be seen that they occur in three groups or "patches." The rotor blade is rotating counterclockwise in this figure, and the first stall patch is seen at about 180 degrees on the inboard portion of the blade. Then as the blade continues around, the stall moves outward on the blade and leaves the tip at an azimuth of about 280 or 290 degrees. The second and third stall patches occur at approximately 350 and 50 degrees, regardless of the type of maneuver. It is concluded that the first stall cycle is triggered by high angles of attack

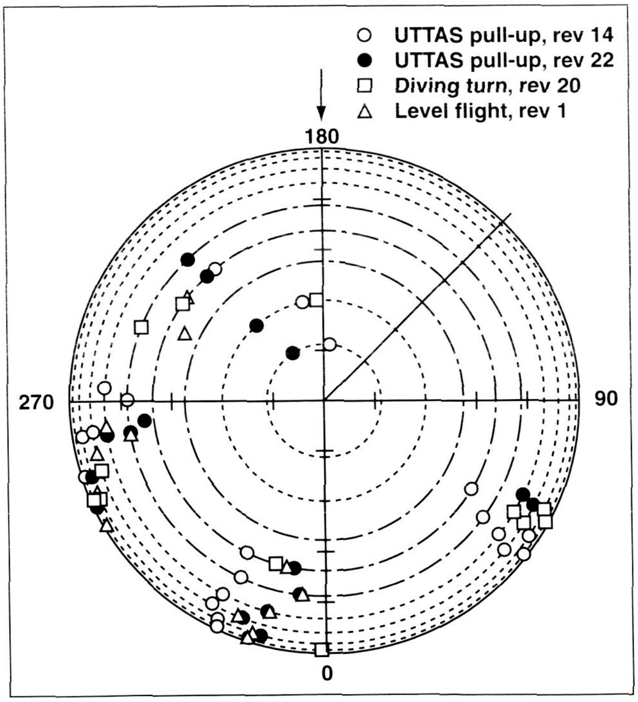

Fig. 1. Rotor map of dynamic-stall locations for four loading conditions.

that are associated with the loading on the blade, whereas the pattern of the second and third cycles is determined by the flexibility of the control system as the twisting forces on the blade cause the blade to oscillate in and out of stall. These results suggest that analytical methods need to be tested for steady flight conditions initially and, if successful there, then applied to maneuvering flight.

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Modeling UH-60A Control System Stiffness

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Accurately predicting the dynamic stall characteristics of a helicopter rotor has become one of the major goals of the rotorcraft industry. The loads during this flight condition are important, for they are used to size the helicopter control system. In addition, improved predictions should reduce the design and development cost of new helicopters. To accurately predict these dynamic stall characteristics, accurate models of the rotor structure, control system stiffness, linear and nonlinear aerodynamics, and rotor inflow are required.

The objective of this work was to focus on improving the control system model of the UH-60A helicopter and thus improve the prediction of its dynamic stall characteristics. The recent flight testing of the UH-60A at Ames Research Center provided a wealth of data on observations of the dynamic stall phenomenon; the data are ideally suited for comparison with calculations from comprehensive rotorcraft analyses. In addition, current models of the UH-60A control system stiffness were based on an analytical estimate and never verified.

A direct measurement of the UH-60A control system stiffness was made, and a summary of the collective loading results is shown in the figure. These data show that the measured collective control-system stiffness is a function of the rotor azimuth, as opposed to the constant value typically used. The data also show that the maximum value of the measured stiffness near 165 degrees rotor azimuth is more than 4 times that used in the current model.

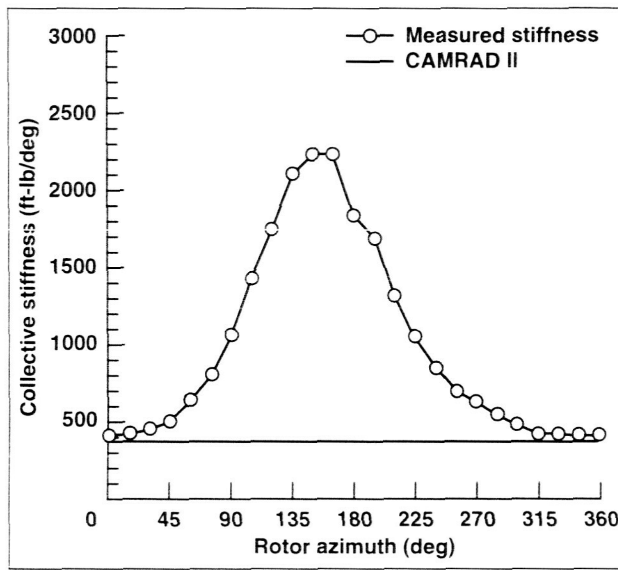

Fig. 1. Measured and calculated UH-60A control-system stiffness versus rotor azimuth.

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